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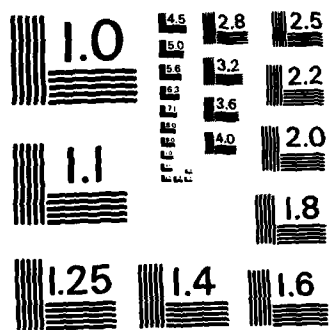
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ILLINOIS INSTITUTE OF TECHNOLOGY

Chicago, Illinois 60616

Contract AFOSR-81-0158

Interim Scientific Report

on

THREE-DIMENSIONAL EFFECTS OF UNSTEADINESS
ON SEPARATED TURBULENT FLOWS

by

John L. Way,

Robert E. Drubka

&

Dennis J. Koga

Department of Mechanical Engineering

July 1982

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Chief, Technical Information Division

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Interim Scientific Report
March 1981 - March 1982

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ON SEPARATED TURBULENT FLOWS

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John L. Way,
Robert E. Drubka
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ABSTRACT

A series of experiments is undertaken to take advantage of previous work and state-of-the-art experimental investigative techniques to provide information on a wide class of unsteady flows. Primary objectives of the program are to answer basic questions concerning the effects of unsteadiness on the subject flows and to provide data in a form which is useful to theoreticians and numerical analysts. The ultimate goals of this project include providing the engineering designer of various devices which involve unsteady flow and separation with the tools of conceptual mechanisms as well as a bank of useful data. Key mechanisms which have already been discovered suggest that large scale structures caused by flow unsteadiness exhibit gradual phase shift with increasing frequency of oscillation and that they convect with faster relative speed in attached shear layers as compared to their speed in separated layers.

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1. Title of Research Effort: Three-Dimensional Effects of Unsteadiness on Separated Turbulent Flows

Principal Investigator: John L. Way

2. Abstract: A series of experiments is undertaken to take advantage of previous work and state-of-the-art experimental investigative techniques to provide information on a wide class of unsteady flows. Primary objectives of the program are to answer basic questions concerning the effects of unsteadiness on the subject flows and to provide data in a form which is useful to theoreticians and numerical analysts. The ultimate goals of this project include providing the engineering designer of various devices which involve unsteady flow and separation with the tools of conceptual mechanisms as well as a bank of useful data. Key mechanisms which have already been discovered suggest that large scale structures caused by flow unsteadiness exhibit gradual phase shift with increasing frequency of oscillation and that they convect with faster relative speed in attached shear layers as compared to their speed in separated layers.

3. Current Work: Flow geometries which involve the effect of large-scale unsteadiness on separated regions are being studied. The basic flow geometry is that of a separating shear layer which later reattaches, and the unsteadiness is provided by an oscillation imposed upon the mean flow. The amplitude and frequency of the mean flow oscillation are varied, as is the scale of the separated flow region.

4. Progress: Research during the first year of this project has progressed along several fronts:

- 1) Modification and improvement of facilities.
- 2) Model manufacture, installation and testing.
- 3) Preliminary results.

A description of work in each of these areas follows:

1) Modification and improvement of facilities: After completion of recent turbulent wake research, the rotating shutter mechanism was re-installed in the Oscillating Flow Tunnel. The shutter mechanism was redesigned to be direct driven by a PMI Magnetics printed circuit motor powered by a DC-rectified Variac autotransformer. A rotary position indicator was installed on the shutter mechanism to provide a signal representative of the instantaneous shutter position. This configuration is capable of producing sinusoidal shutter displacements in the frequency range from 1 to 10 Hz with less than 6% harmonic distortion in an unblocked test section. The corresponding freestream velocity fluctuations are only approximately sinusoidal with less than 25% total harmonic

distortion. These harmonic distortion differences between the driving shutter rotation and resultant velocity fluctuations are due to the nonlinear response of the wind tunnel itself, along with a minor sub-harmonic factor attributable to the asymmetry of the shutter blades (since one shutter blade rotation causes two oscillatory flow cycles). In addition to the distortion analysis in the unblocked test section, it was found from two point probe data that there is no phase or amplitude variation between the quarter and mid-span positions in the test section, indicating that the oscillation waves are propagating one-dimensionally in the streamwise direction.

The above measurements were obtained with the 4 inch shutter blade set, which represents a 67% tunnel blockage with the blades closed (16% blockage with the blades open). These shutter blades, when utilized with a one inch rearward facing step model configuration, produced freestream velocity fluctuations ranging from 2% to 15% depending on the freestream velocity and the shutter frequency. The 15% fluctuation peak occurs at approximately 3 Hz flow oscillation frequency and an additional smaller resonance occurs near 10 Hz for all freestream velocities.

Based on these freestream velocity fluctuation and oscillatory distortion measurements, it is apparent that some type of active control must be implemented to produce a more controlled, purer sinusoidal velocity oscillation. Towards this goal, a compatible PMI servo power amplifier has been obtained to provide a feedback system controller for the shutter mechanism. In addition, a Data Translation DT1716 digital-to-analog converter board has also been acquired to allow the PDP-11 Fast Acquisition System the possibility of computer-controlling the shutter motion.

This new feedback, control, and driving mechanism for the shutters in the Oscillating Flow Tunnel will allow the possibility of producing actively controlled continuous or one-shot velocity oscillations of a sinusoidal, triangular, step, or arbitrary-type waveform. In addition, the servo control allows the capability of oscillating the shutter blades rather than rotating them. This will have the advantage of minimizing current sub-harmonic distortion of the freestream velocity oscillations.

2) Model manufacture, installation and testing: A flat-plate with adjustable rearward-facing step has been constructed and tested in the I.I.T. Oscillating Flow Wind Tunnel. The plate has an elliptical leading edge and adjustable flap at its downstream end. The nose and flap are designed to be used in conjunction with other wind-tunnel manipulators to produce a flow which remains attached to the upper surface of the plate throughout the cycle of freestream oscillation, and to thus guarantee unseparated flow ahead of step. Phase-conditioned documentation of the flow ahead of and in the vicinity of the step has been obtained using flow visualization techniques over a range of step heights and freestream oscillation amplitude and

frequency. The visualization diagnostics confirm that the flow remains attached throughout the oscillation cycle over a wide range of operating conditions.

Additional models have been manufactured for other facilities by undergraduate students working on Semester Projects related to this study. Rearward-facing step models, fixed gate models and flapper gate models have been installed in the I.I.T Oscillating Water Tunnel. A flapper gate model has been installed in the I.I.T. Water Table facility. These models are described in the MMAE 402 Semester Project Reports listed in Section 5b of this report.

3) Preliminary results: Smoke-wire flow visualization was used to study the flow in the vicinity of a 2.54 cm two-dimensional rearward-facing step. A vertical smoke-wire was situated in the plane of the step and the visualization was phase conditioned to the shutter position, as described earlier, in equal 15 degree increments. This was undertaken to characterize the nature of the flow under various operating conditions. Cases were studied when the boundary layer at the step was laminar and also when it was fully turbulent. The freestream oscillation amplitude was initially set at 4% of the undisturbed freestream velocity although the tunnel has the capability of being operated between amplitudes of 2% and 15% when the shutters are rotating continuously. These values can be reduced even further when the shutters are harmonically oscillated about a mean shutter position. The oscillation frequency was varied to cover nondimensional frequencies, N_f , of 0.001 and 0.1. This matrix of conditions covered the extreme cases to be explored in this study. The visualization clearly indicated the variability in the formation of the separated layer, the spatial development of the shear layer, and the reattachment zone to the above conditions.

Results for a low frequency, $N_f = 0.04$, laminar boundary layer case were analyzed quantitatively. These indicated that the unsteady induced structures in the initial separated flow region convect downstream at a constant speed of 0.4 times the mean freestream speed. Once the separated layer reattaches, approximately 7.5 step heights downstream, these structures once again convect downstream at a constant speed, but now the speed is 0.8 times the mean freestream speed.

These encouraging results demonstrate that a great deal of global information will be obtained when later visualization is analyzed with the available digital image processing capabilities, thus providing a bias-free examination of the visualization records.

An internal report by Koga and Way (see section 5b) was generated on steady and oscillating flow over an oscillating airfoil. Phase-conditioned smoke-wire flow visualization photographs were obtained for an airfoil oscillating ± 10 degrees about a 15 degree mean angle of attack in both steady and oscillating freestream flows. Comparison of the

phase-conditioned photographs between the various oscillation cases has shown that increasing the airfoil oscillation frequency resulted in a phase delay in the formation of the airfoil leading edge separation bubble and resultant free-vortical flow structures. The addition of synchronized freestream oscillation also had the effect of phase-shifting the large-scale flow structure formation so that combinations of oscillating flow with an oscillating airfoil and steady flow with an oscillating airfoil at a slightly higher frequency (about 50% increase) produce nearly identical flow visualization results. In most case comparisons, it was also found that the phase-shift process was modulated over the oscillation period with the fastest shifting occurring near the phase-time of the leading edge separation bubble formation.

5a. Presentations:

"Reconstruction and Processing Techniques for Sparsely Sampled Low-Wavenumber Structures," by D. J. Koga, R. W. Wlezien and J. L. Way, presented at the 34th Meeting of the American Physical Society Division of Fluid Mechanics, Monterey, CA, November 1981; abstract appears in APS Bulletin Vol 26, No 9.

5b. Reports:

"Visualization of Steady and Oscillating Freestream Flow over an Oscillating Airfoil," by D. J. Koga and J. L. Way, I.I.T. Internal Report No. 81-1 for AFOSR-81-0158, I.I.T., Chicago, Il., Nov. 1981.

"Motion of the Separated Shear Layer over a Rearward Facing Step in an Unsteady Mainstream Flow," by P. Vogel and A. Brankovic, MMAE 402 Semester Project Report, I.I.T., Chicago, Il. May 1981.

"Experimental Visualization of Turbulent Flow Separations in Oscillating Flows," by P. J. Fajardo and T. Donovan, MMAE 402 Semester Project Report, I.I.T., Chicago, Il., December, 1981.

"A Phase-Conditioned Flow Visualization Study in Oscillating Flow," by R. Brokopp, W. Pomierski and D. Szczesniak, MMAE 402 Semester Project Report, I.I.T., Chicago, Il., May, 1982.

"Visualization of Turbulent Flow Separation from an Oscillating Flow," by E. Bonnema, D. Gill, M. Kapolnek and R. Prazak, MMAE 402 Semester Project Report, I.I.T., Chicago, Il., May 1982.

6. Contributors:

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